Bound Waves and Microwave Backscatter from the Ocean

William J. Plant
Applied Physics Laboratory
University of Washington
1013 NE 40th St
Seattle, WA 98105-6698
phone: 206-543-7836 fax: 206-543-6785 plant@apl.washington.edu

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http://nt-waves.apl.washington.edu

LONG-TERM GOALS

Our long-range objective is to detect and understand sea surface signatures produced by a variety of natural and man-made causes.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are to investigate the generation and propagation of bound waves and turbulent breaking regions and to understand their role in microwave backscatter from the ocean. Bound waves and turbulent breaking regions are types of small-scale surface roughness that are carried along by longer waves. They are distinct from the much-studied short wind waves that produce most microwave backscatter from the ocean but propagate at their intrinsic phase speed, which is significantly slower than the speed of longer waves.

APPROACH

Our approach is to carry out field and laboratory measurements combined with modeling to attempt to define the origin and characteristics of bound waves and turbulent breaking regions and to determine their effect on microwave backscatter from wind-roughened water surfaces. Comparison of microwave and infrared measurements is also carried out in order to determine the relationship between bound waves and microscale breaking as defined by IR detection of skin layer disruption.

WORK COMPLETED

The first of our field experiments was carried out on the CIRPAS Twin Otter airplane during ONR's Shoaling Waves Experiment in November 1999. Some results from that experiment were shown in last year's report. The second experiment was carried out on FLIP in September and October 2000. It consisted of simultaneously observing the same sea surface spot with low-incidence-angle IR and high-incidence-angle microwaves to determine the relationship between bound waves and microscale breaking. An initial survey of the data collected has now been carried out and indicate that the data will probably be sufficient to meet our objectives.

We have also spent considerable time this year analyzing laboratory data collected in 1996 in the wind wave tank at the Canada Centre for Inland Waters. These data have yielded definitive information on

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threshold and hysteresis effects in wind wave growth and decay. A paper detailing our results was written in the past year and has now been submitted for publication to the Journal of Physical Oceanography (Donelan and Plant, 2001).

Finally, we completed work on the initial phase of the multiscale model and submitted it for publication to the Journal of Geophysical Research (Plant, 2001). It has now been accepted. The article describes the model in detail in a form that is applicable to low and moderate incidence angles. We are presently working to extend the model to higher incidence angles by including bound wave effects. Next year we will include Doppler spectral calculations in the model in order to model the temporal and spatial variability of these spectra.

RESULTS

We will defer until next year a presentation of results from our FAIRS measurements. Instead we will show results here from the threshold and hysteresis wave tank studies and from the most recent exercising of the multiscale model.

The wavetank work has shown that with increasing wind speed, microwave backscatter increases dramatically at a wind speed threshold determined by the difference between wind input to and viscous dissipation from the short waves that scatter microwaves. The measurements demonstrate, though, that in a decreasing wind, backscatter can exist at wind speeds well below the threshold for an increasing wind. This effect is illustrated in Figure 1 where cross sections are plotted versus wind speed for winds that are increasing and decreasing at two different rates.

Our work has shown that one reason for this hysteresis effect is that short waves cannot initially grow until the subsurface flow transitions from laminar to turbulent, an effect that is not present for a decaying wind. However, another effect is also present. This is the presence of bound waves that decay at a rate that is indicative of the viscous decay rate of their parent wave and is slower than their own viscous decay rate. Our measurements have shown that bound waves are present at surprisingly low wind speeds.

Figure 2 shows contour plots of wave height variance spectral density versus wavenumber and frequency for winds near the threshold. These spectra were obtained using a wavelet technique developed by Donelan et al., 1996 applied to point height and slope measurements. Contours are 5 dB apart, red asterisks indicate the no wind dispersion relationship for freely propagating waves, red circles indicate this dispersion relationship with the effects of wind added (Plant and Wright, 1980), and the blue pluses indicate the dispersion relationship of waves traveling at the speed of the dominant wave in the tank. The dominant wave of the spectrum is indicated by the open blue circle. Figure 2a is at a wind speed below that at which exponential wave growth can occur. In Figure 2b, exponential wave growth is just able to take place and the presence of contours stretched out along the dispersion relationship of waves traveling at the dominant wave speed indicates that bound waves have already begun to form. These waves, once formed, will decay only when the longer wave that generates them decays.

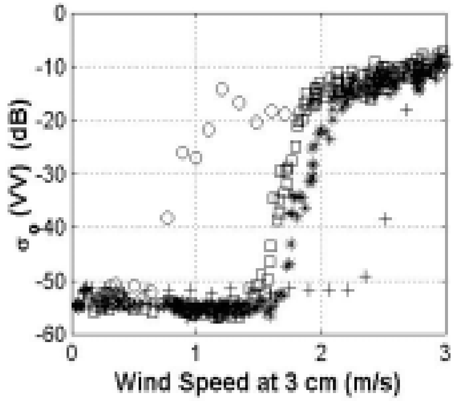

__Figure 1. Hysteresis of the radar cross section under increasing and decreasing winds observed in CCIW wind wave tank. Asterisks indicate a wind increasing at a rate of 0.32 cm/s, squares show the same wind decreasing, pluses indicate a wind increasing at a rate of 3.61 cm/s, and circles show the same wind decreasing. Clearly the faster the wind speed changes, the larger the difference between the results for increasing and decreasing winds, i.e., the hysteresis.__

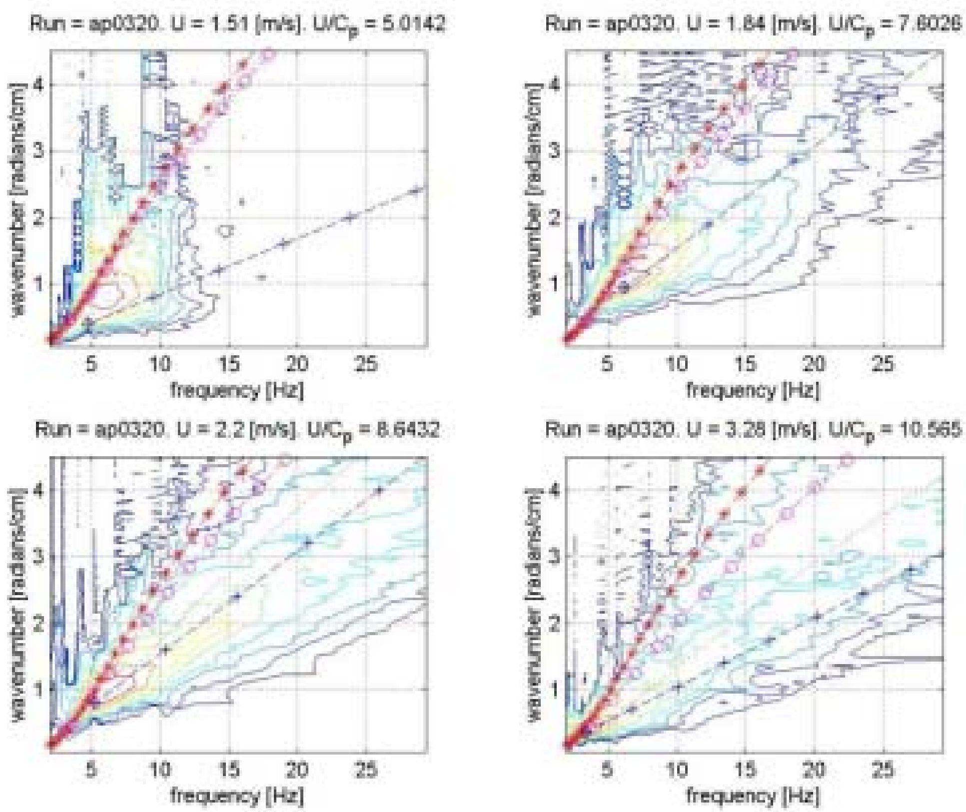

__Figure 2. Wavenumber/frequency spectra of surface wave height obtained from point height/slope data using the wavelet technique of Donelan et al., 1996__

Turning now to additional results from the multiscale model that have been obtained this year, Figure 3 shows data at a very different microwave frequency than those at which the model has been exercised in the past. Data in this figure are shown as dashed and dash-dotted lines while multiscale model predictions are the symbols (* = VV, o = HH) and the solid line is the prediction of the standard quasi-specular theory. The data were taken with NASA's 36 GHz Scanning Radar Altimeter (SRA) with VV polarization and reported by Banner et al., 1999. Unfortunately, the SRA is uncalibrated and only the angular dependence of relative received power was reported by Banner et al. The dashed line shows their data while the dash-dotted lines show the data converted to cross section. Both these data and the quasi-specular result have been slid vertically to match multiscale model results at nadir. Figure 3a is up/downwind at a wind speed of 6.8 m/s, Figure 3b is up/downwind at 15.4 m/s, and Figure 3c is crosswind at 15.4 m/s. For reference, an incidence angle of 20 degrees yields ϑ^2 = 0.0.122 rad^2.

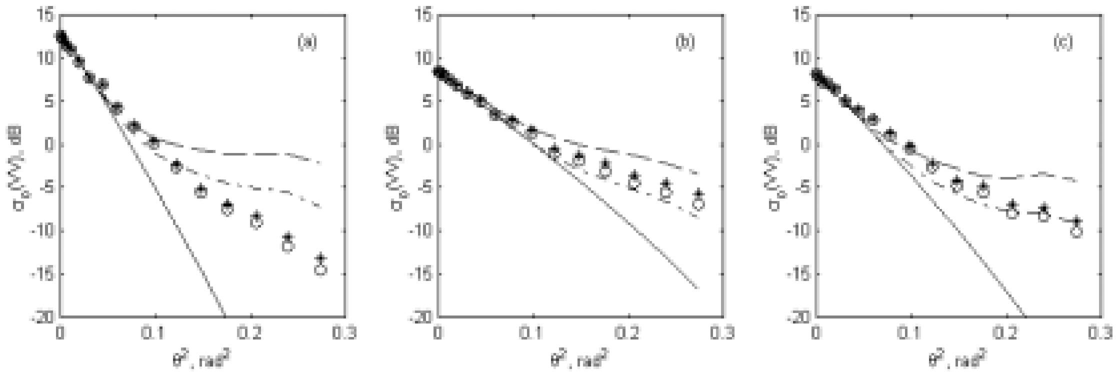

Figure 3. Data taken with NASA's 36 GHz Scanning Radar Altimeter at VV polarization (dashed and dash-dotted lines) compared with the multiscale model (symbols) and with quasi-specular theory (solid line).

Clearly the multiscale model follows the data better out to 20 degrees than quasi-specular theory does. Beyond this angle the data may be somewhat in question since the SRA is designed to look at low incidence angles and may approach a noise level at higher angles. At lower microwave frequencies, the multiscale model predicts VV cross sections at angles between 20 and 50 degrees to within about a dB.

IMPACT/APPLICATION

Our results shed new light on microwave backscattering from the ocean under a variety of environmental and system conditions. Thus they are applicable to any microwave radar that senses the ocean surface. In particular, they promise to aid our understanding of the imagery of signatures of surface and subsurface vehicles, especially in the higher incidence angle region where bound waves become most important.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

This project is directly related to NASA scatterometers, such as the NSCAT, QuikScat, and SeaWinds. Data collected under this funding have been used in an NSCAT-related project to attempt to develop better model functions and retrieval methods for scatterometers at low wind speeds.

The radar system, CORAR, the prototype of which was developed under this project, provided the primary data relating to our objectives in the November, 1999 ONR Shoaling Waves Experiment.

Finally, this project has many parallels with a project run by the Office of the Secretary of Defense to investigate the microwave signatures produced by submarines. The basic understanding of microwave scattering, especially at high incidence angles, produced in this project furthers these attempts to detect submarines.

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